

Optimization of FAST Electron Gun Beam Parameters

Lucas Kang – Brown University

Introduction

The FAST (Fermilab Accelerator Science and Technology) Facility includes a superconducting RF linear accelerator. This accelerator's test beamlines downstream will provide venues for advanced accelerator R&D (AARD) and future planned experiments like IOTA [1].

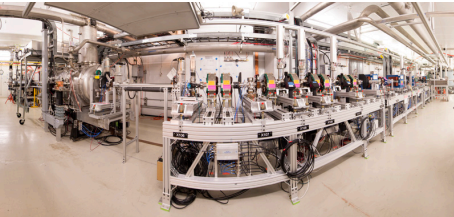


Figure 1: Image of Cyro Module and beam line, FAST Cave Configuration at NML. Photocathode electron gun and toroid monitor to the left, beam travels to the right.

Photoinjector Gun

The RF photocathode electron gun is identical to the gun developed at DESY Zeuthen (PITZ), and is a normal-conducting 1½ cell 1.3 GHz gun.

The electron gun is routinely operated at peak gradients of 40-45 MV/m, with an output beam energy of ~5 MeV. Additionally, it utilizes a feedback system to regulate temperature to better than ±0.02 °C for beam and phase stability.

The photocathode is a 10 mm diameter polished molybdenum disk coated with Cs₂Te with 5 mm diameter photosensitive area. It is illuminated by 263 μm wavelength laser light directed onto the photocathode downstream of the RF coupler [1].

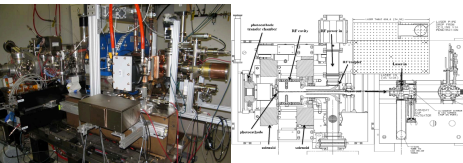
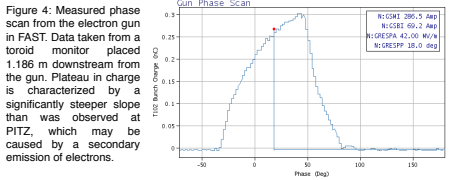


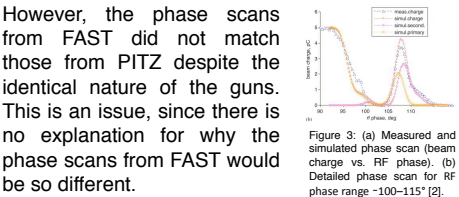
Figure 2: (a) Photograph of the gun installation in the FAST enclosure on August, 2012. Photocathode preparation chamber is to the left, and beam exits to the right. RF waveguide connection is towards the viewer (white blank-off). Solenoids are blue [1]. (b) Cross section of gun, solenoids, transfer chamber, and downstream instrumentation [1]. Toroid monitor placed before the Faraday Cup to measure beam intensity/charge.

The Problem

To measure beam intensity, a toroid monitor was utilized to conduct a phase scan (accelerated charge measured as a function of launch phase). In order to optimize gun operation, the RF phase of the gun was varied with respect to the laser across various phase scans (See Figure 4).



Faraday Cups and integrating current transformers (ICT) had been used at PITZ to measure the electron beam charge.



One possible explanation for the discrepancy in the recorded data is a Schottky-like effect manifesting itself in the Cs₂Te photocathode.

The Schottky effect describes the lowering of the work function or the potential barrier of a metal by an external electric field, which leads to an increased electron emission from the metal. This phenomenon may explain the unexpected results observed in the phase scan above. The charge of a bunch is determined at the time of emission as:

$$Q = Q_0 + SRT_{Q_{Schottky}} \cdot \sqrt{E} + Q_{Schottky} \cdot E$$

where E is the combined longitudinal electric field in the centre of the cathode. The charge Q₀ is the charge of the macro particles as defined in the input distribution (rescaled to fit Q_{bunch}) [3].

Parameter Optimization

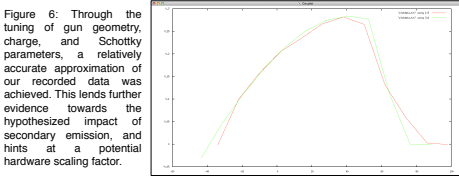
ASTRA (A Space Charge Tracking Algorithm) is written in Fortran 90 by Klaus Floettmann (DESY).

A program was developed that allows for the simulation of the FAST beam through a Monte-Carlo approximation utilizing ASTRA, as well as real-time manipulation of parameters, and regression analysis, to try to explain our recorded data with the consideration of secondary emission.

Using this, a set of parameters was found that relatively accurately describes the behavior of the accelerator, and hints towards a potential hardware scaling factor. The program also began shedding some light on the problem of secondary emission, though arriving at a conclusion may warrant more investigation in the future.



Figure 5: The optimization program, first written in Python, was translated to C in order to more efficiently process the large amounts of raw data that ASTRA outputs per simulation. Now, it acts as an environment in which bash script and analysis can be run side-by-side.



Future Work

The program above, as well as the parameters it found, will continue to predict future experimental readings and diagnose issues. As FAST strives for higher intensities and more bunches, this work will set the stage for future optimization.

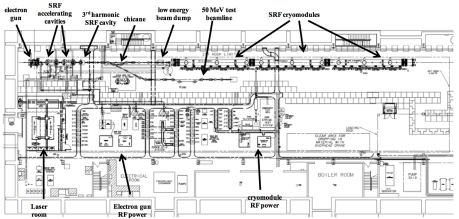


Figure 7: Upstream floor plan of the FAST photoinjector and 3 SRF cryomodules in the original building footprint. The beamline is 1.2 m above the floor, the floor is 6.1 m below grade, and the building length is 74 m [1].

References

1. Mike Church, et al. 2012. *Design of the Advanced Superconducting Test Accelerator*.
2. K. Abrahamyan, et al. 2006. *Experimental characterization and numerical simulations of the electron source at PITZ*. Nuclear Instruments and Methods in Physics Research, Volume 558, Issue 1.
3. J. Li, et al. 2012. *Emission Study of Photocathode RF Gun at PITZ*. Proceedings of ICAP2012.